CEDs yielding a mean population per CED of 990 persons. From these field studies, approximately 11,000 individual signal field intensities were determined from a total of 373 measurement sites. Figure 1 illustrates the type of field intensity data collected; in this case the spectral data show one of the measurements of the FM broadcast band obtained in Portland. Here each spectral peak observed is a single FM radio station signal. In this particular case the measurement site was very near to a multiple broadcast transmission center and the measured power density was 14 μW/cm^2. Table 2 summarizes the relevant information pertaining to each city investigated.

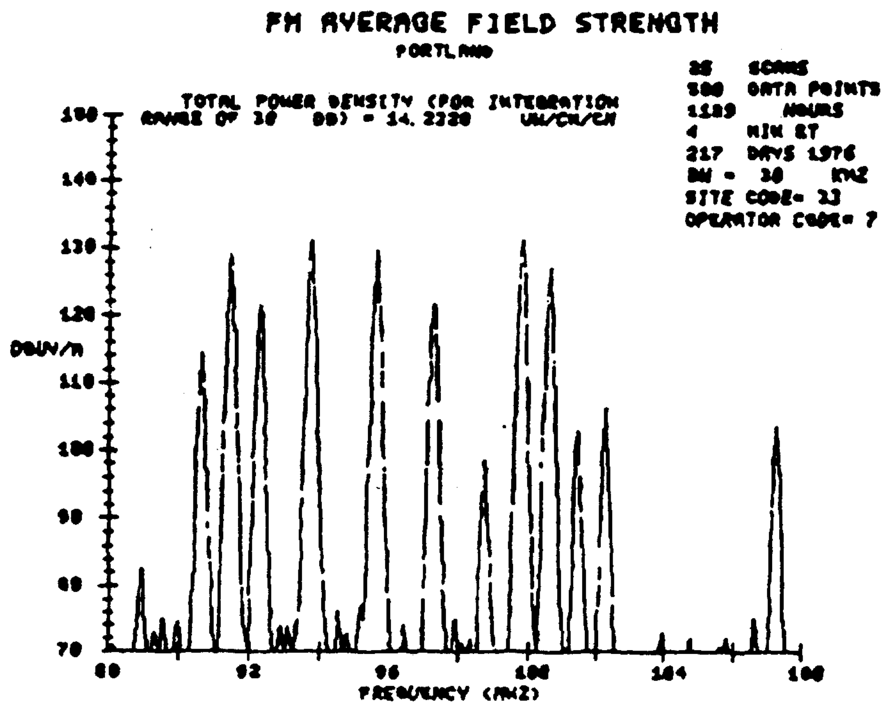

Figure 1. Measured FM radio broadcast field intensity spectrum in Portland, Oregon

TABLE 2. SUMMARY OF INFORMATION RELEVANT TO ENVIRONMENTAL RF AND MW FIELD STUDIES

City	#CEDs	Population	# of Field Strength Values	Number of Stations FM	Low VHF	High VHF	UHF	Total	# of Sites
Boston	2003	1953665	252	14	3	1	3	21	9
Atlanta	1249	1221431	396	11	2	2	3	18	16
Miami	1897	1661012	448	13	3	2	2	20	16
Philadelphia	3606	3407059	941	17	2	2	3	24	31
New York	11470	12269374	1426	23	3	4	3	33	36
Chicago	4646	4743905	1378	20	2	3	3	28	39
Washington	2291	2516917	1107	17	2	2	3	24	37
Las Vegas	356	264501	632	6	2	3	0	11	42
San Diego	1113	1071887	956	17	1	2	2	22	38
Portland	1194	818040	816	12	3	3	0	17	38
Houston	1127	1265933	810	14	1	3	2	20	33
Los Angeles	7596	6951121	1801	29	3	4	7	43	38
TOTAL	38548	38144845	10963	193	26	31	31	281	373

MODELING METHOD

Athey et al., (1978) described a method whereby the actual measurement data were used to modify a presumptive propagation model for calculation at all CED sites throughout a city. Athey's report made use of a propagation model form which was obtained by analyzing measured field intensity data obtained in Miami which suggested a classically recognized decrease in electric field intensity with increases in distance between FM broadcast stations and measurement sites. This form for the model was then applied to data obtained in all VHF and UHF broadcast bands to determine exposure. In the present case, we have developed an enhanced method for predicting exposure at the various CEDs by taking into consideration the fact that each city and individual stations possess their own distinctive propagation characteristics.

The method we have used includes the following features. For each station under consideration, the field intensity obtained for the station at each measurement site is used to obtain a linear, least squares fit of the data. This provides a functional form describing the way by which the electric field strength varies as a function of distance from the station. Since this model is generated from actual measurement data for each station, note that no specification of transmitter power or antenna height is necessary. If, by chance, because of poor data, i.e., high variability in measured values of field strength, the resulting computed slope of the least squares fit is positive, the slope is changed arbitrarily to be equal to zero. This in general is not a common problem, occurring in only 12 instances for the entire set of measurements reported. Next, the straight line model is used to calculate the field intensity which would be expected at each CED within the cities' bounds. From extensive tests we determined that maximum accuracy was usually obtained in the modeling procedure by using the predetermined slope of the line model but shifting this line model vertically to form a least squares fit with the measurement data obtained in the neighborhood of the calculational point (a CED location). We observed that this shifting process was effective in reducing the uncertainty whenever the particular station was closer than 5 km to the CED. Thus we incorporated this feature of appropriately shifting the line model to best fit the measurement data obtained at the two nearest measurement sites. Tests revealed a non-significant reduction in uncertainty by shifting the model to best fit more than the two nearest sites. The effect of this process is to lend weight to the local measurement data in improving estimates primarily of high intensity exposures. It was found that the shifting technique produced little, if any, apparent improvement in other than the higher exposure levels. If it occured in the calculational process that a CED was identified as being closer than 100 meters from a nearby station, then the actual distance was arbitrarily changed to correspond to 100 m. This was accomplished to protect against the erroneous computation of very high exposure levels when the CED - station distance was very short.

An important feature in the development of our work was the construction of a test program which could be used to estimate the uncertainty associated with the modeling method. In lieu of performing additional measurements to examine the accuracy of the method, we elected to make use of the metropolitan area measurements themselves in a special way. The process consists of starting at one specific measurement site where data has been obtained and then creating the least squares line model for each station based on the measurements obtained at all other measurement sites, but not including the site under test. The exact calculational process described above is then used, always rejecting any data obtained at the test site, to arrive at the estimated field strength for each station. Then, a direct comparison is made between the predicted field and the field strength actually measured at the site. This is accomplished for each station involved and in addition to individual signal field strength differences, a comparison is made between the predicted total power density of exposure and that actually measured and being the result of exposure from all signals present at the site. The process is then repeated at each other measurement site to obtain an indication of the goodness of the modeling procedure. Once the process has been completed for all measurement sites in a city, the results are assessed statistically by determining the mean deviation between actual and predicted field strengths and the mean deviation between actual and predicted total power densities of all signals. These results are then used as an indicator of the quality of the more comprehensive calculations performed at all CEDs within a city. Undoubtedly, the variances of the deviations apparent in this process are partly due to the immediate location variability discussed previously. Longely (1976) has discussed this subject in detail.

Repeated application of the test program, using different criteria for shifting, provided the insight by which the final modeling criteria were determined. Extensive computer time was spent before arriving at the optimum criteria.

POPULATION EXPOSURE RESULTS

The aforementioned modeling method was applied to the measurement data obtained in each of the 12 cities. Exposure levels were computed at each CED location and the resulting exposure was assumed to apply to all of the population associated with each CED. After calculation of the exposures the number of persons associated with various ranges of intensities were determined; in particular, approximately one-third decadic power density ranges were used to classify exposure, i.e., 0.001, 0.002, 0.005, 0.010, 0.020, 0.050, 0.100 $\mu W/cm^2$, etc. The final results of the analysis are presented in terms of the accumulative fraction of the population which are potentially exposed equal to or less than these different one-third decadic power density intervals. Results for each of the cities under study are presented in Figures 2-13 wherein the exposure level is plotted logarith mically and the population fraction follows a near normal distribution. Figure 14 provides the results for all cities taken together.

Each figure provides the population exposure determined for each band separately and for all measured bands together. The results suggest that the exposure levels are approximately normally distributed and reveal the interesting finding that of the exposure contributed by the various VHF and UHF broadcast bands, the FM radio broadcast band is clearly discernable as being most responsible for overall exposure, particularly at the highest exposure levels. This finding supports the earlier proposition offered by Tell and Janes (1975) implicating FM radio broadcast transmissions as generally dominant in creating the highest ground levels of RF fields. Despite the lower effective radiated powers authorized for FM broadcasting compared to other VHF and UHF television emissions, a combination of relatively low tower heights and broad vertical antenna radiation patterns for FM transmission conspire to produce these relatively high fields. It is also interesting to note the relatively low contribution provided by the UHF TV band in as much that UHF television stations in the US carry the maximum power authorizations.

In our experience we have found it informative to discuss these results using two different indices. The first is the median exposure level, i.e., that power density at which 50 percent of the population are exposed less than and 50 percent are exposed greater than. The second is the measure of the fraction of the population potentially exposed above 1 $\mu W/cm^2$. The data for total band exposure presented in Figures 2-14 have been summarized from the point of view of these two indices in Table 3. The most significant results are for the accumulative population of all the cities in which a median exposure of 0.005 $\mu W/cm^2$ was determined while something less than 1 percent of the population are apparently exposed at intensities greater than 1 $\mu W/cm^2$. It is worthy to reemphasize that these data apply only to the domestic broadcast service in the US and cannot account for population mobility. Though the population data base itself is dated, we feel that the results are probably representative for the actual present distribution of population.

The results of the test program designed to estimate the uncertainty associated with exposure calculations are presented in summary form for the 12 cities in Table 4. The tabulated data refer to the average of all individual field strength deviations and power density deviations at all measurement sites within each city. The observed high deviation in power density calculations in Boston undoubtedly reflects the few measurement sites used in that study.

In order to assess the uncertainty in our overall estimates of population exposure for all cities studied to date, Figure 15 was prepared which provides the frequency of occurrence of deviations between measured and calculated values of exposure at all 373 sites visited. Figure 15 shows that the distribution of these uncertainties is approximately chi-squared in nature suggesting that the population of power densities from which these determinations were obtained is normally distributed, this being in consort with the general appearance of Figure 14. The most significant point of Figure 15 is that the most likely uncertainty appears to be about 3dB while 70 percent of all our exposure calculations are within 8dB.

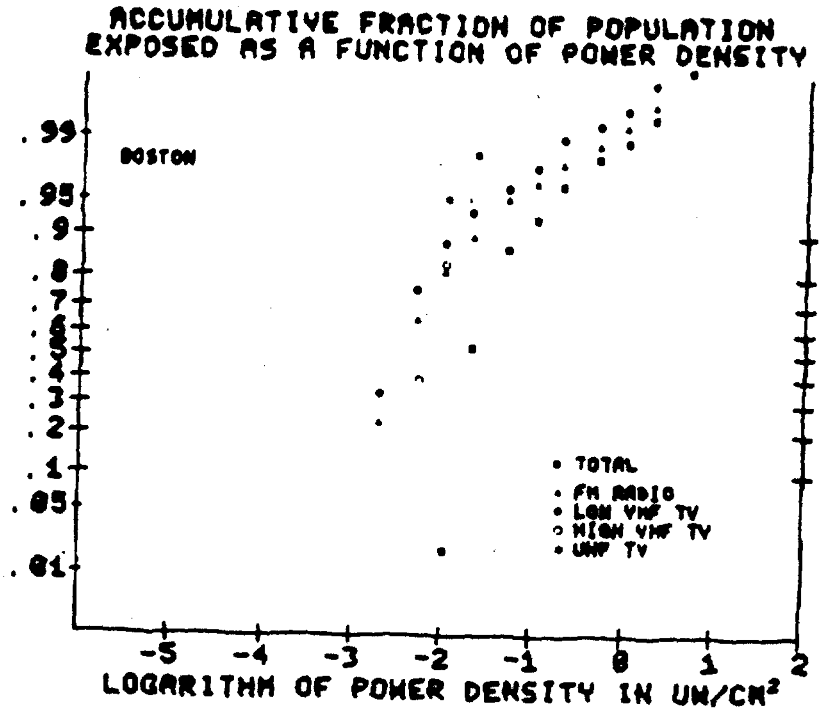

Figure 2. Accumulative fraction of population in Boston exposed ≤ log S(μW/cm²)

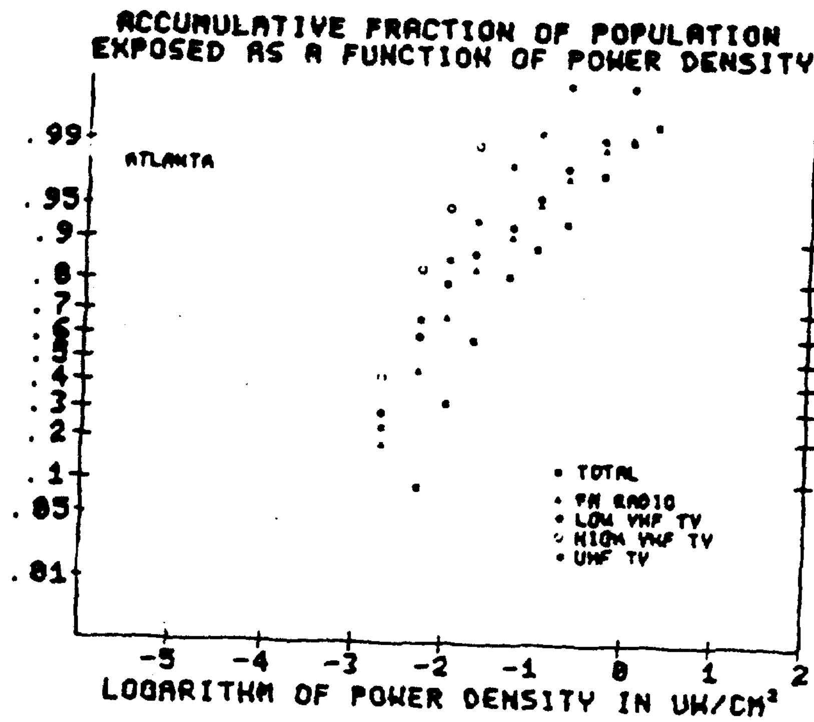

Figure 3. Accumulative fraction of population in Altanta exposed ≤ log S(μW/cm²)

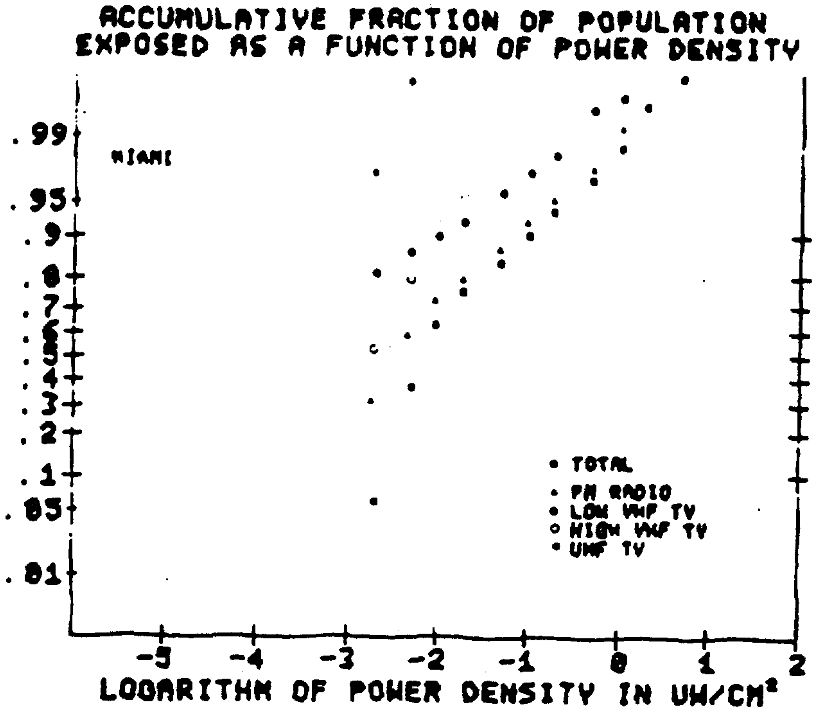

Figure 4. Accumulative fraction of population in Miami exposed ≤ log S(μW/cm²)

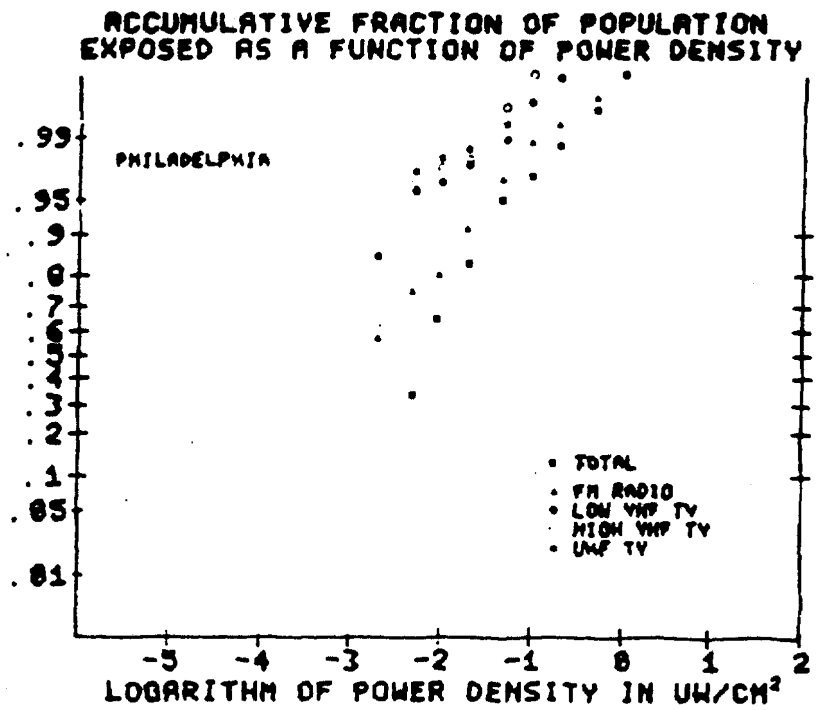

Figure 5. Accumulative fraction of population in Philadelphia exposed ≤ log S(μW/cm²)

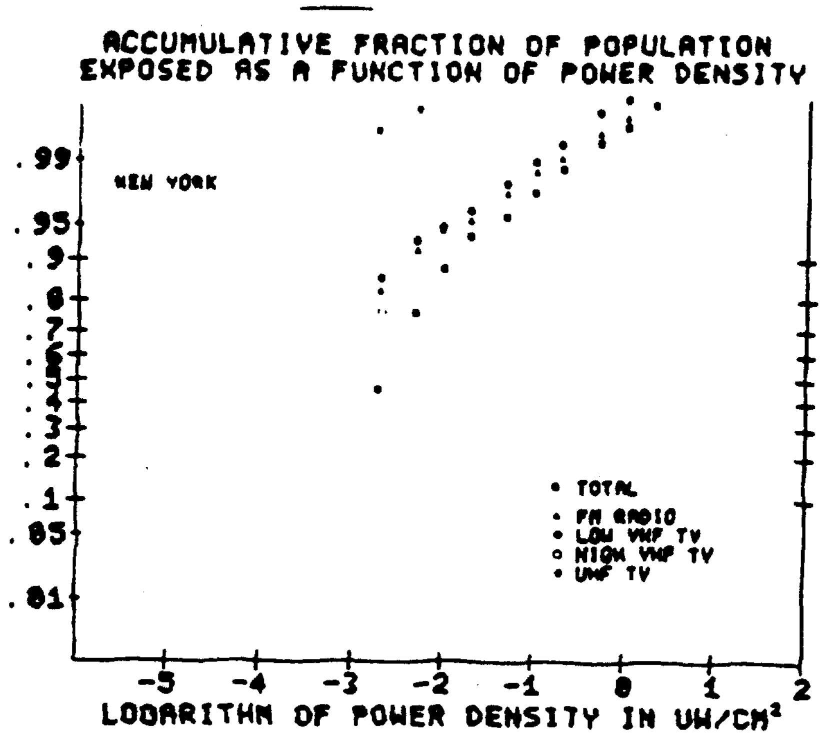

Figure 6. Accumulative fraction of population in New York exposed ≤ log S(μW/cm²)

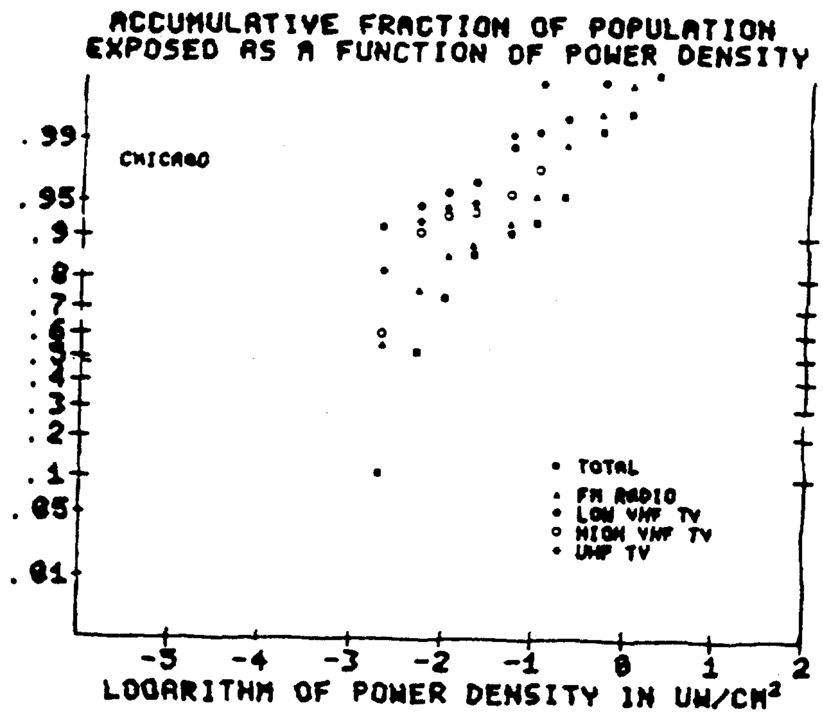

Figure 7. Accumulative fraction of population in Chicago exposed ≤ log S(μW/cm²)

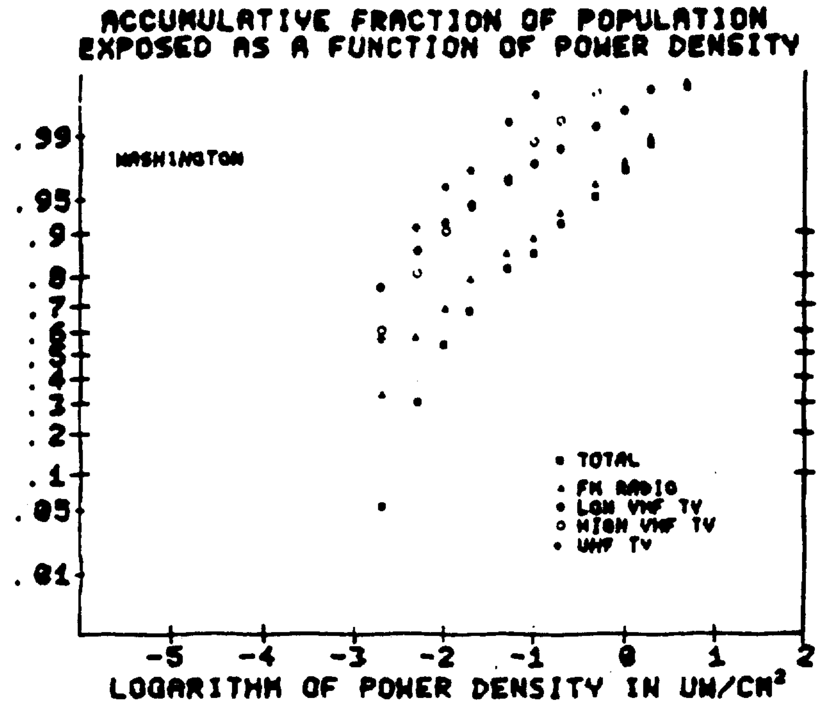

Figure 8. Accumulative fraction of population in Washington exposed ≤ log S(μW/cm²)

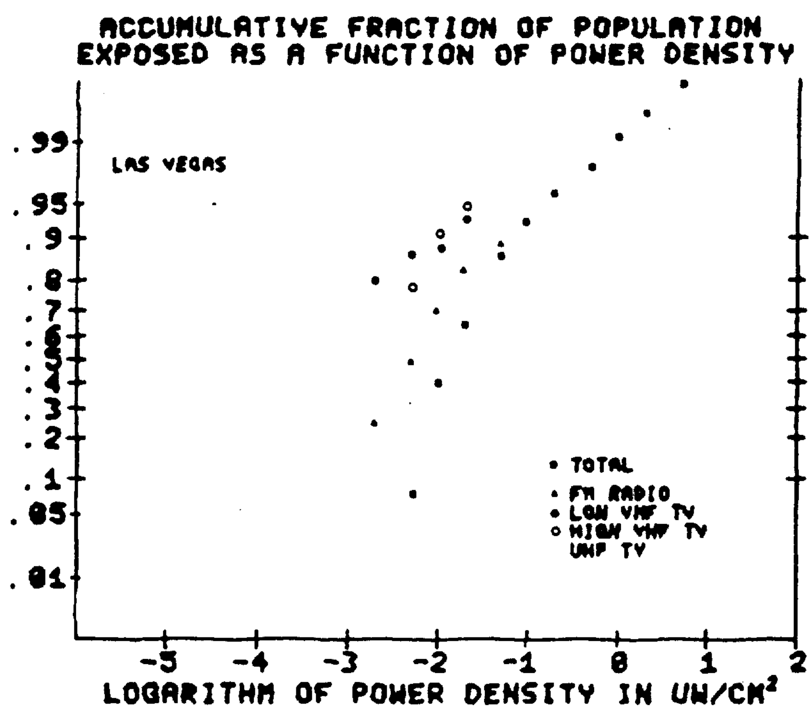

Figure 9. Accumulative fraction of population in Las Vegas exposed ≤ log S(μW/cm²)

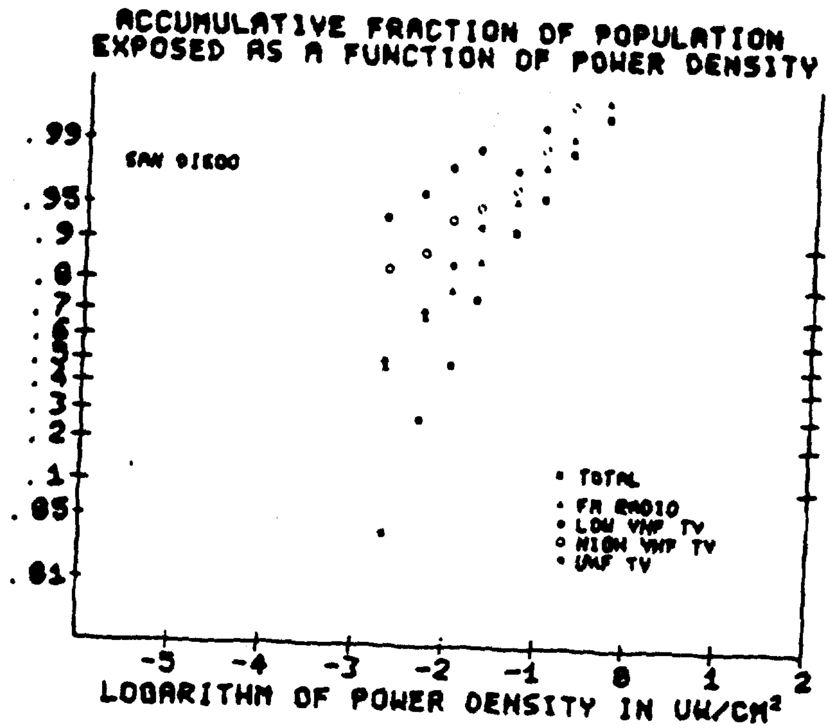

Figure 10. Accumulative fraction of population in San Diego exposed ≤ log S(μW/cm²)

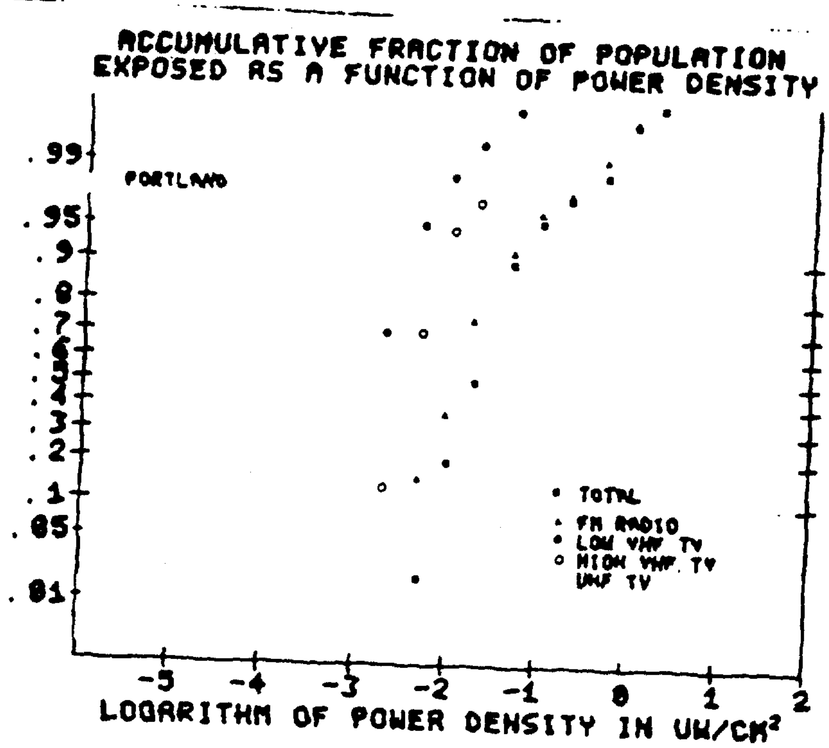

Figure 11. Accumulative fraction of population in Portland exposed ≤ log S(μW/cm²)

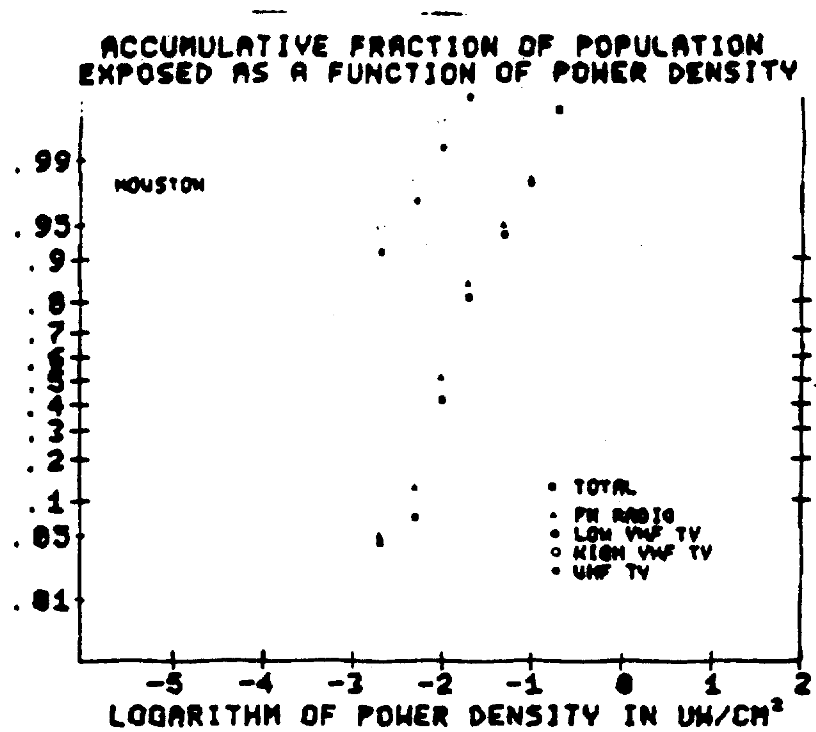

Figure 12. Accumulative fraction of population in Houston exposed ≤ log S(μW/cm²)

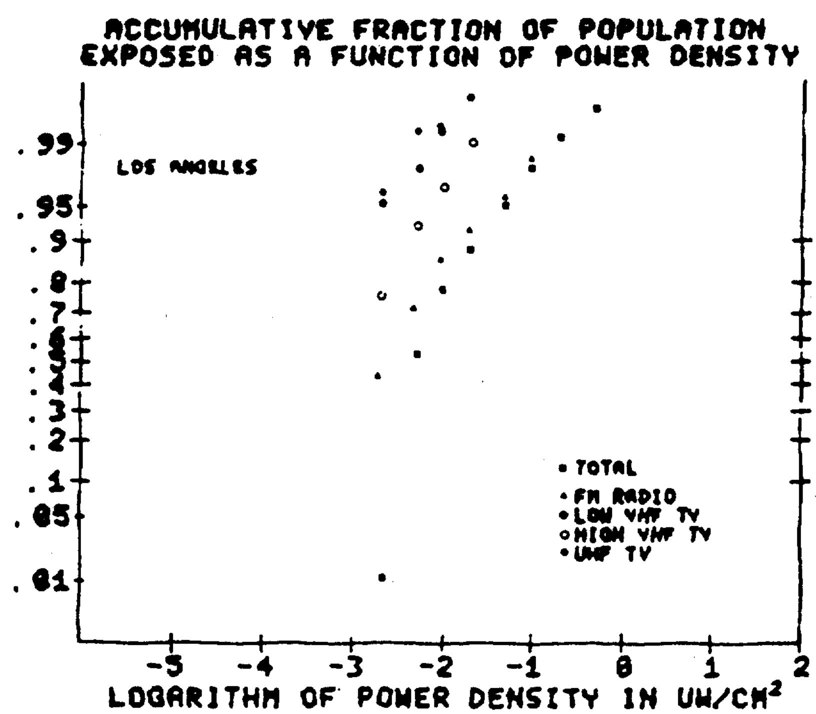

Figure 13. Accumulative fraction of population in Los Angeles exposed ≤ log S(μW/cm²)

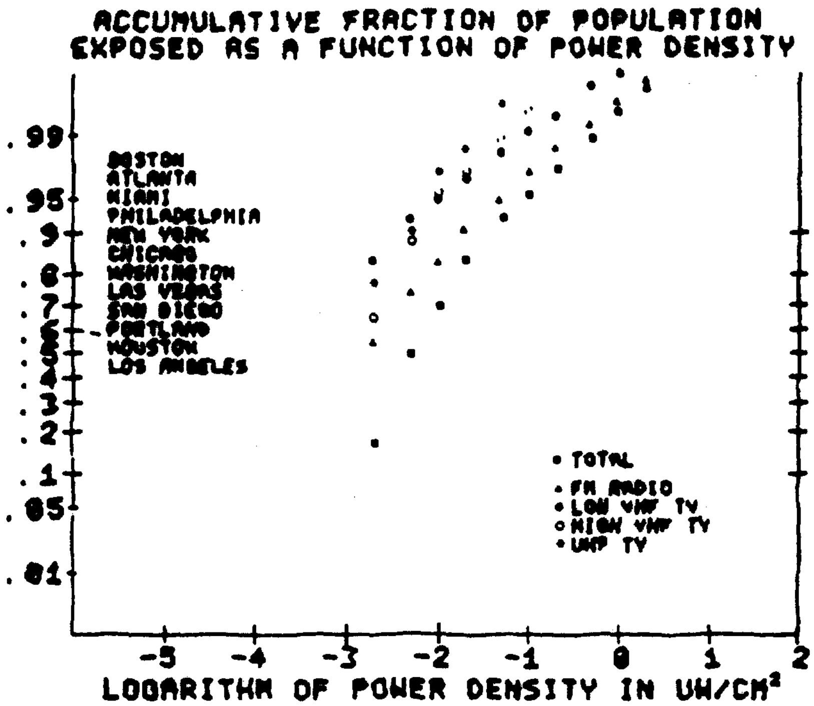

Figure 14. Accumulative fraction of population in 12 cities exposed $\leq$ log S($\mu W/cm^2$)

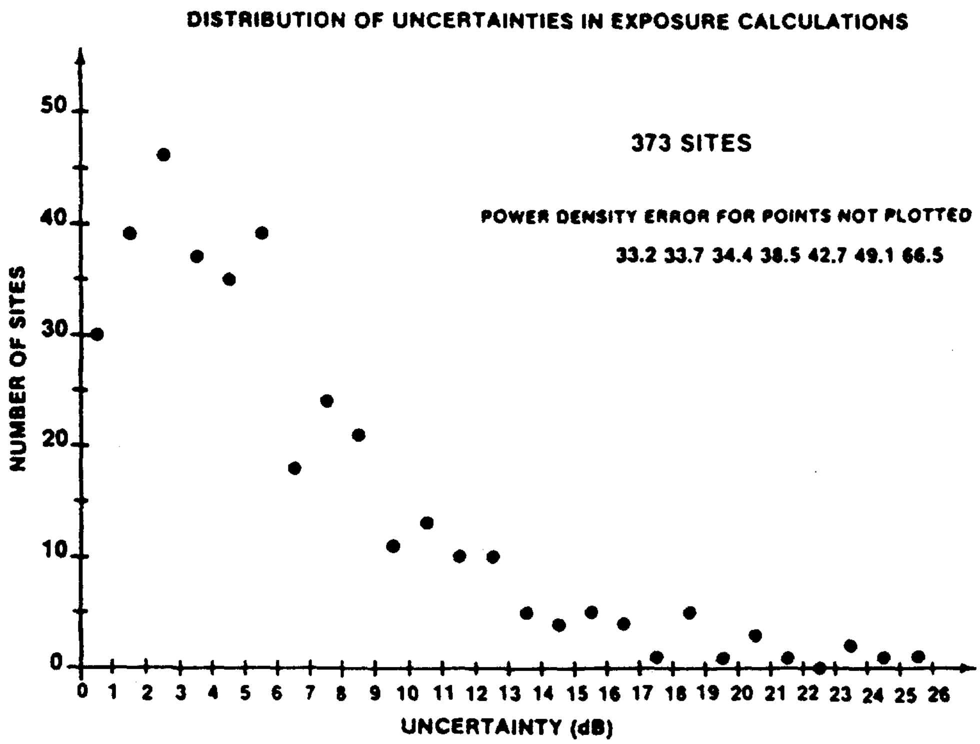

Figure 15. Distribution of uncertainties in exposure calculations

TABLE 3. POPULATION EXPOSURE RESULTS IN 12 CITIES

City	Median Exposure (μW/cm²)	Percent of Population Exposed ≤1 μW/cm²
Boston	0.018	98.50
Atlanta	0.016	99.20
Miami	0.0070	98.20
Philadelphia	0.0070	99.87
New York	0.0022	99.60
Chicago	0.0020	99.60
Washington	0.009	97.20
Las Vegas	0.012	99.10
San Diego	0.010	99.85
Portland	0.020	99.70
Houston	0.011	99.99
Los Angeles	0.0048	99.90
All cities	0.0053	99.99

TABLE 4. SUMMARY OF EXPOSURE TEST PROGRAM RESULTS

City	No. Sites	Mean Field Error (dB)	Mean Power Density Error (dB)
Boston	9	11.9	16.8
Atlanta	16	5.8	4.4
Miami	16	6.5	7.6
Philadelphia	31	7.3	6.9
New York	36	7.2	6.2
Chicago	39	6.9	7.6
Washington	37	6.1	5.5
Las Vegas	42	7.2	5.2
San Diego	38	8.4	10.5
Portland	38	9.7	5.2
Houston	33	7.3	5.6
Los Angeles	38	5.8	6.6

DIRECT ESTIMATION METHOD

Our choice of the population weighted random method for selection of CEDs as measurement sites was prompted by a desire to establish a consistent approach from city to city. In the beginning phases of the metropolitan area studies, measurement sites were not chosen on this basis but were decided upon by common sense and the apparent distribution of population as infered from city maps. An interesting observation from application of the computer selection method, however, is that if measurements are conducted at locations which are truly random in the population space, then a simple inspection of the measurement data according to sites should provide a direct assessment of population exposure in the general area. To illustrate this process, measurement sites corresponding to CEDs (most do) are sorted according to increasing power density and the accumulative fraction of sites are plotted against the logarithm of power densities on probability paper. Figure 16 provides an example of this method applied to data obtained in Los Angeles. From the data, which is seen to be almost perfectly log-normally distributed, one obtains a median exposure value of about 0.006 $\mu W/cm^2$ which compares favorably with the most comprehensive method which necessitates many calculations at all CEDs in the area. Note that this method, after the initial site selection is completed, requires no further information on population. We have observed a generally good agreement between the two approaches in determining population exposure, particularily near the median exposure values, and often utilize the direct method, in favor of its simplicity, to obtain preliminary estimates of results.

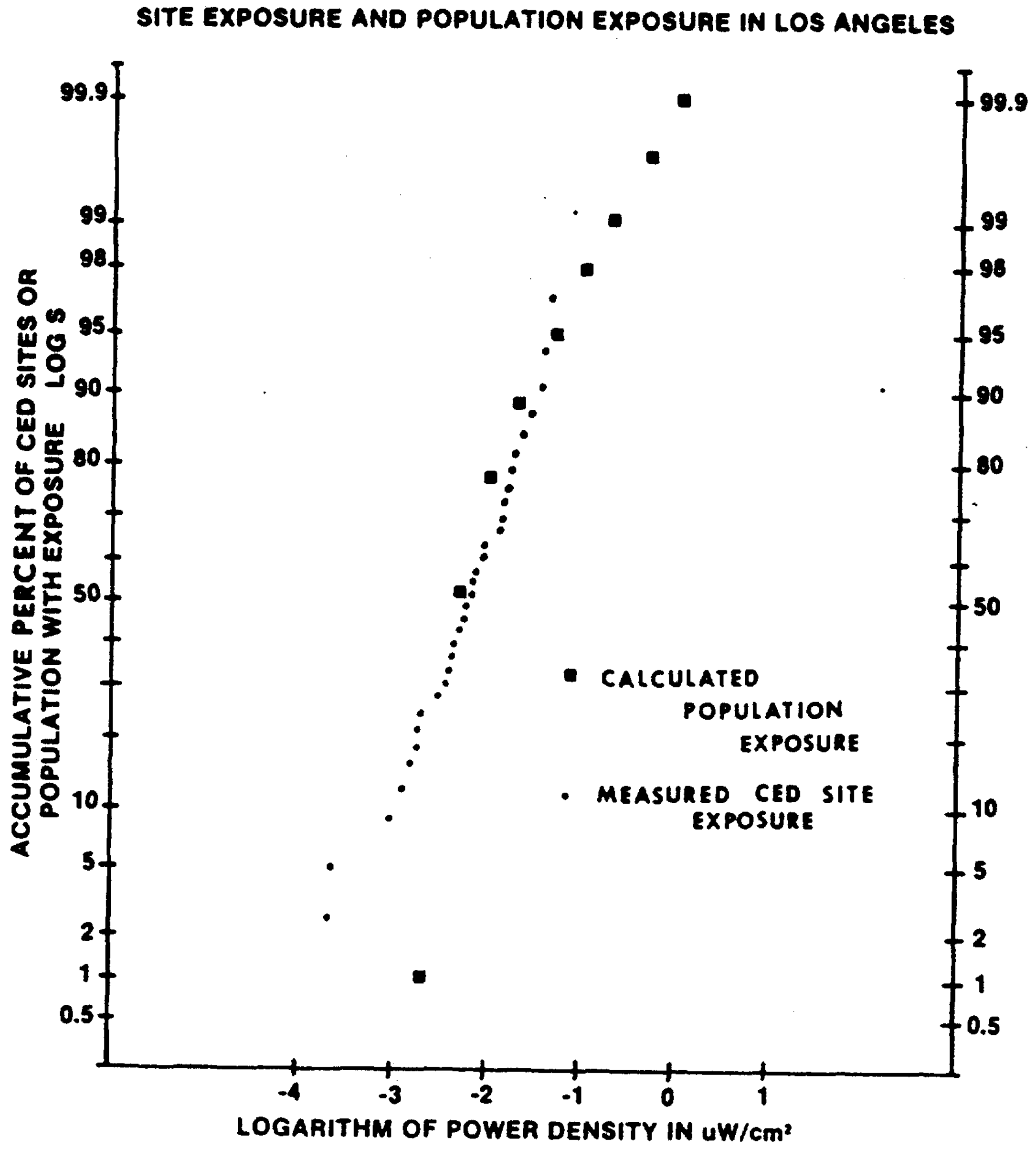

Figure 16. Site exposure and population exposure in Los Angeles

CONCLUSIONS

Results of the methods outlined here suggests that, of the population group studied, representing 18 percent of the total US population, a median exposure value of about 0.005 $\mu W/cm^2$ time averaged power density exists and perhaps, more interestingly, less than 1 percent of the population are potentially exposed at levels above 1 $\mu W/cm^2$. It is observed that the FM radio broadcast service is responsible for most of the continuous illumination of the general population. Indeed, that fraction of the population exposed beyond 1 $\mu W/cm^2$ needs more careful definition and the absolute maximum intensities observed demand precise determination, but it is interesting to note from our results that, even at this time, at least 99 percent of the population studied are not exposed to levels above the suggested level of safety established in the USSR of 1 $\mu W/cm^2$ (Gordon, 1974). Additional data obtained by the USEPA, in special areas wherein mainbeam illumination of tall buildings occur nearby various high power broadcast installations, has shown that it is difficult to find areas where intensities exceed 100 $\mu W/cm^2$ (Tell, 1978).

These data must be viewed from the standpoint of long term exposure and certainly, it is true that, on occasion, localized exposures may greatly exceed 1 $\mu W/cm^2$. The authors recognize the case of limited time exposure of some individuals to microwave oven leakage, portable or mobile communication equipments, and various other sources of RF and MW exposure including pulsed sources, however, we feel that at this time, there do not exist adequate quantitative techniques for evaluating these more extreme exposure regimes in terms of their impact on our population exposure estimates provided in this report. It is our observation that these higher intensity situations must be addressed on the basis of the length of time spent in the field and will require an accentuated emphasis upon field measurements conducted from the viewpoint of determining absolute maximum exposure values that may be encountered such as inside building measurements.

FUTURE WORK

The evidence provided by the rather extensive environmental measurements program conducted by the USEPA within the US seems to overwhelmingly support the contention that most of the general population is not chronically exposed to high intensity (i.e., >100 $\mu W/cm^2$) RF and MW radiation. Accordingly, future field measurement efforts will include to a greater extent examination of those unique kinds of exposure circumstances wherein relatively high intensity exposures are possible or expected. A more detailed investigation of environmental levels of pulsed RF and MW fields is currently being developed. Additionally, we are examining our data from the viewpoint of developing deterministic propagation models, provided transmitter effective radiated power and antenna height, for different classes of transmitting stations. Our particular interest is in being able to more accurately model close-in exposure conditions, and in this connection we will be comparing our data and resulting propagation models with other existing models (Kalagian, 1976).

REFERENCES

Athey, T.W., R.A. Tell, N.N. Hankin, D.L. Lambdin, E.D. Mantiply, and D.E. Janes (1978): "Nonionizing Radiation Levels and Population Exposure in Urban Areas of the Eastern United States." Environmental Protection Agency Technical Report ORP/EAD-77-008, May.

Gordan, Z.V. (ed.): Biological Effects of Radiofrequency Electromagnetic Fields, translated from Moscow O Biologicheskom Deystruii Elektromagnitnykh Poley Radiochastot in Russian No. 4, 1973. Available Through NTIS as JPRS Document 63321, October 30, 1974.

Janes, D.E., R.A. Tell, T.W. Athey, and N.N. Hankin (1977a): "Radio-frequency Radiation Levels in Urban Areas," Special Supplement in biology to Radio Science, editors A.W. Guy and D.R. Justesen, SS-1 (in press) 1977.

Janes, D.E., R.A. Tell, T.W. Athey, and N.N. Hankin (1977b): "Nonionizing Radiation Exposure in Urban Areas of the United States," Communication 304, accepted for presentation in Session No. S.07, Nonionizing Radiation, IVth International Congress of the International Radiation Protection Association, 1977.

Kalagian, G.S. (1976): "Field Strength Calculation for TV and FM Broadcasting (Computer Program TVFMFS)." Federal Communications Commission Technical Report FCC/OCE RS 76-01, Washington, DC, January.

Longley, A.G. (1976): Location Variability of Transmission Loss-Land Mobile and Broadcast Systems." Department of Commerce, Office of Telecommunications Report OT 76-87, May.

Tell, R.A. (1976): "A Measurement of RF Field Intensities in the Immediate Vicinity of an FM Broadcast Station Antenna." Technical Note, ORP/EAD-76-2, U.S. Environmental Protection Agency, Silver Spring, MD, January (NTIS Order No. PB 257 698/AS)*.

Tell, R.A. (1978): "Measurements of Radiofrequency Field Intensities in Buildings with Close Proximity to Broadcast Stations," Environmental Protection Agency Technical Note, April.

Tell, R.A., and D.E. Janes (1975): "Broadcast Radiation: A Second Look." In Biological Effects of Electromagnetic Waves, ed. by C.C. Johnson and M.L. Shore, (Selected papers of the USNC-URSI 1975 annual meeting, Boulder, CO, October (2 Volumes), USDHEW Publication (FDA) 77-8011.

Tell, R.A. and J.C. Nelson (1974a): "RF Pulse Spectral Measurements in the Vicinity of Several Air Traffic Control Radars." EPA Technical Report EPA-520/1-74-005, 45 pages, May.

Tell, R.A., and J.C. Nelson (1974b): "Microwave Hazard Measurements Near Various Aircraft Radars." Radiation Data and Reports, Vol. 15, No. 4, pp. 161-179, April.

Tell, R.A., N.N. Hankin, J.C. Nelson, T.W. Athey, and D.E. Janes (1976a): "An Automated Measurement System for Determining Environmental Radiofrequency Field Intensities II." In Proceedings of NBS symposium on Measurements for the Safe Use of Radiation. March 1976, NBS publication NBS SP456, (ed. S.P. Fivozinsky), pp. 203-213. Also presented at 1974 Meeting at USNC/URSI, October 14-17, 1974, Boulder, CO.

(Please read instructions on the reverse before completing)

1. REPORT NO.

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE

POPULATION EXPOSURE TO VHF AND UHF BROADCAST RADIATION IN THE UNITED STATES

5. REPORT DATE

June 1978

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

Richard A. Tell and Edwin D. Mantiply

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

U.S. Environmental Protection Agency
Office of Radiation Programs
Electromagnetic Radiation Analysis Branch
P.O. Box 15027
Las Vegas, Nevada 89114

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

Same as above

13. TYPE OF REPORT AND PERIOD COVERED

Technical Note

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The U.S. Environmental Protection Agency has been collecting broadcast signal field intensity data for over two years to estimate population exposure to this form of nonionizing radiation. Measurement data have been obtained at 373 locations distributed throughout 12 large cities and collectively represent approximately 11,000 measurements of VHF and UHF signal field intensities. The VHF and UHF broadcast service is the main source of ambient radiofrequency exposure in the United States. A computer algorithm has been developed which uses these measurement data to estimate the broadcast exposure at some 39,000 census enumeration districts within the metropolitan boundaries of these 12 cities. The results of the computations provide information on the fraction of the population that is potentially exposed to various intensities of radiofrequency radiation. Special emphasis has been placed on determining the uncertainty inherent to the exposure estimation procedure and details are provided on these techniques. A median exposure level (that level to which half of the population is exposed greater than) of 0.005 $\mu W/cm^2$ time averaged power density has been determined for the population of the 12 cities studied, the cumulative population of which represents 18 percent of the total United States population. The data also suggest that approximately 1 percent of the population studied, or about 380,000, are potentially exposed to levels greater than 1 $\mu W/cm^2$, the suggested safety guide for the population in the USSR. Alternative techniques of using the measurement data to estimate population exposure are examined and future extensions of this work are discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

CLINICAL AND HYGIENIC ASPECTS OF EXPOSURE TO ELECTROMAGNETIC FIELDS

(A Review of the Soviet and Eastern European Literature)[1]

CHRISTOPHER H. DODGE

Biosciences Division, U.S. Naval Observatory, Washington, D.C. 20390

INTRODUCTION

It has long been apparent that electromagnetic fields impose a health hazard, especially at field intensities greater than approximately 15 mW/cm^2, which cause thermal (heating) responses in the organism. Only quite recently it is suspected, from the Soviet and East European literature, that these fields might also elicit certain functional or so-called "specific" responses, especially in the nervous system, at field intensities less than 10–15 mW/cm^2, which do not cause heating.

Prior to 1964, no comprehensive effort had been attempted in this country to review the world (especially the Soviet and East European) literature on the general biological effects of microwaves. Soviet literature was in most cases scattered, quite difficult to locate, and consequently had never come to the attention of the U.S. scientific community. When in 1964, one of the first reviews on this subject was attempted by the writer, then affiliated with the Library of Congress, it was speculated by some authorities on the subject that an extremely low yield of literature would result from the attempt. It was therefore quite surprising that a search of the Soviet and Eastern European literature on the biological effects of microwaves revealed a large and virtually unexploited body of information which had never come to the attention of the U.S. scientific community. The first review (1) contained 132 references to Soviet and East European work on this subject. Subsequent reviews by the author (2–4) and a number of others (5–9) revealed that some of the most active research in the world was being conducted in the Soviet Union and some of the Eastern European countries.

It is the purpose of this paper to review Soviet and Eastern European studies of the effects of radiofrequency fields on the human organism. An attempt will be made to summarize the more noteworthy findings of some of the literally hundreds of published works devoted to this subject and to underscore the need for a more critical and systematic treatment of this subject. This review will concentrate nearly exclusively on human clinical studies and occupational hygiene surveys and will not consider the more theoretical or experimental aspects of the biological effects of microwaves.

BACKGROUND

As early as 1933, certain Soviet scientists had already recognized that electromagnetic fields affected the human nervous system. In 1937, Turlygin (10) published one of the first comprehensive Soviet accounts of the effects of centimeter waves on the human central nervous system. He found that CNS excitability was increased by 100% of the control level when a crude spark oscillator in the vicinity of the head of a subject was switched on. In a lengthy review article, Livshits (11) cited no fewer than 28 Soviet publications on the general subject of clinical and biological microwave effects which had been published by the end of the 1930's.

During the 1940's and early 1950's, there was an understandable lull in research on this subject due to World War II. By the middle and late 1950's, there appeared a veritable deluge of Soviet literature dealing, in the main, with the clinical and hygienic aspects of microwave exposure which has continued unabated to this day. By the early 1960's, the Eastern European countries of Czechoslovakia and Poland had also become extremely active in the area of microwave exposure effects. In a cursory

[1] The views expressed by the author do not necessarily represent those of the U.S. Navy.